An Assessment of Fecal Coliform Bacteria in Cruise Ship Wastewater Discharge

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Abstract-The Science Advisory Panel (SAP) evaluated the potential for microbiological environmental and public health impacts of wastewater discharges from large passenger ships. Historically, fecal coliform bacteria have been used to indicate the presence of sewage in environmental waters and as an index of the sanitary quality of the water. Because fecal coliform are always found in the intestinal tract of warm-blooded animals, they signal the presence of wastewater and the potential presence of other microorganisms capable of causing diseases including viruses. The discharge and fate of fecal coliform from large passenger ships was examined in the context of Alaska state standards related to secondary contact through recreation and primary contact through consumption of raw shellfish. Available data, coupled with relevant dilutions, did not indicate that large passenger ship discharges would cause violations of the recreational water quality standards, and recommendations were made aimed at minimizing risks to shellfish areas.

I. INTRODUCTION

Protection of marine resources is crucial to all states with such resources. In response to Alaskans' concern about the potential compromise of pristine environments into which cruise ships transport visitors, a stakeholder group formed the Alaska Cruise Ship Initiative in 1999. This initiative required investigation, understanding and oversight of discharges from large cruise ships into the waters of Alaska. As part of the overall assessment of impacts from cruise ship waste discharges on the environment, a Science Advisory Panel (SAP) looked at fate and transport of microorganisms that would be present in a ship's wastewater. Relevant public health scenarios resulting from exposure to these wastewater microorganisms as measured by the indicator group known as coliform bacteria were identified. Indicator bacteria concentrations were measured in an on-board sampling program and evaluated in the context of Alaska's bacteriological standards for recreational contact and shellfish harvesting. A dispersion model was constructed that takes into account the nearly instantaneous dilution following discharge of the wastewater. Overall, the goal of this evaluation was to determine whether mitigation alternatives were needed and, if so, which method might be the most effective.

II. DISCUSSION

Coliform bacteria have been used to indicate the presence of sewage in environmental waters and as an index of the sanitary quality of water for more than 100 years. Fecal coliform are a subgroup of the total coliform group. The functional definition of fecal coliform is based on the ability of the bacteria to produce turbidity and gas from lactose in a liquid medium within 24 ± 2 hours at 44.5 ± 0.2 °C [2]. Experience has shown that the genera of bacteria fitting the fecal coliform definition are from the genera *Escherichia* and *Klebsiella*. These genera along with *Citrobacter* and *Enterobacter* make up the total coliform group [2]. Total coliform and fecal coliform are not necessarily responsible for illness in the population, but because they are always found in the intestinal tract of humans and other warm-blooded animals their presence indicates the potential for exposure to other pathogenic (disease causing organisms) microorganisms that might also be shed from the gastrointestinal tract.

Alaska's water quality standards for bacteria were established to protect humans from gastrointestinal illnesses caused by fecal pathogens and are based on the designated uses of the water. However, unless a water body has been classified such that a particular standard is not applicable or has been modified for particular uses, the most stringent standard applies. The standards are:

A) *Aquaculture*

For products normally cooked, 200 fecal coliform (FC)/100 ml as a geometric mean[1] for samples over a 30-day period with no more than 10% of the samples exceeding 400 FC/100 ml.

For products not normally cooked, 20 FC/100 ml as a geometric mean for samples over a 30-day period with no more than 10% of the samples exceeding 40 FC/100 ml.

B) *Seafood processing*

20 FC/100 ml as a geometric mean for samples over a 30-day period with no more than 10% of the samples exceeding 40 FC/100 m1.

[1]"geometric mean" means the n^{th} root of the product of a series of n numbers; e.g. (2 X 9 X 5) ^1/3=4.48

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C) *Industrial uses*

200 FC/100 ml as a geometric mean for samples over a 30-day period with no more than 10% of the samples exceeding 400 FC/100 ml.

D) *Contact recreation*[2]

100 FC/100 geometric mean for samples over a 30-day period with no more than 10% of the samples exceeding 400 FC/100 ml.

E) *Secondary recreation*[3]

200 FC/100 ml as a geometric mean for samples over a 30-day period with no more than 10% of the samples exceeding 400 FC/100 ml.

F) *Harvesting of raw mollusk or other raw aquatic life for human consumption*

Based on a 5-tube decimal dilution test, the median[4] MPN may not exceed 14 FC/100 ml, and not more than 10% of the samples may exceed a median MPN of 43 FC/100 ml.

The standard for consumption of raw mollusk or other raw aquatic life is derived from the National Shellfish Sanitation Program (NSSP) requirements promulgated by the Food and Drug Administration (FDA). The NSSP is a cooperative State-FDA-Industry program for the certification of shellfish beds for commercial harvest. The NSSP standards say that either the geometric mean or the median[4] can be used.

Alaska recently adopted fecal coliform effluent standards for commercial passenger vessels. These standards are not to be confused with water quality standards. Rather they are performance standards the treatment technologies are required to attain. Unlike water quality standards, effluent standards do not allow consideration of dilution in implementation nor do they have any relation to the use and exposure scenarios in Alaska's water quality standards. These effluent standards are:

A) *Federal*[5] *and State of Alaska standards*[6] *for large commercial passenger vessels (overnight accommodations of 250 or more passengers)*

200 FC/100 ml graywater and treated blackwater discharged from vessels traveling at 6 knots and at least one nautical mile from the nearest shore.

If the effluent meets the most stringent standards under Coast Guard regulations, the vessel may discharge at less than 6 knots and within 1 mile of the shoreline if the fecal coliform 30-day geometric mean does not exceed 20/100 ml.

B) *State of Alaska*[7] *standards for small commercial passenger vessels (accommodations for between 50 and 249 passengers)*

200 FC/100 ml for graywater and treated blackwater. These standards will be effective January 1, 2004.[8]

Alaska's bacteria standards are composed of limits based on geometric mean or medians and frequencies of events where the single sample concentration exceeds a level of concern. Implicit in these standards is that multiple measurements are made over time. Averaging multiple sample results over time helps to overcome the challenges presented by the extreme temporal variability of the fecal coliform signal [7], large ranges in values affecting data distribution and the fact that public exposure to any contamination event can only be determined after exposure has occurred due to the fact that analytical results take at least 24-hours to obtain. Factors such as sunlight, rain, indigenous animal populations, predation by other organisms, sedimentation, wave action and others all impact fecal coliform concentrations on a variable time scale. In addition, rainfall, sewage discharges or presence of a large animal population moving into an area can result in extreme range variation in the analytical data. It is possible for fecal coliform levels to be below detection limits in one sample and multiple millions in the next. Such large swings in analytical results create a skewing of the data distribution. The reliability of statistics based the central tendency of a data set is affected if the data set is not normally distributed [6].

One method used to deal with such a skewed data record is to transform the individual measurements into their logarithm, perform the statistical analyses then transform the data back to its original form [5].

Setting microbiological standards based on median values is another way to deal with the large ranges typical in these data sets. Also, because exposure to microbial contamination is whatever that level is at the time rather than an average over multiple days, medians are useful when assessing human health risks posed by a particular sampling location [3].

Fecal coliform discharges from cruise ships were considered in the context of Alaska's standards in order to identify and address those situations that pose real water quality concerns. An understanding of this

[2] "contact recreation" means activities in which there is direct and intimate contact with water, including wading, swimming, diving, water skiing, and any intimate contact with water directly related to shoreline activities.

[3] "secondary recreation" means recreation activities in which water use is incidental, accidental, or sensory, including fishing, boating, camping, hunting, hiking, and vacationing.

[4] "median" is the value in a data set that splits a data set in half, such that half of the reported values are above the median and half are below.

[5] 33 CFR 159 Subpart E

[6] Alaska Statute 46.03.460 (b) & (c)

[7] 33 CFR 159.309 (b)

[8] Alaska Statute 46.03.460-490, uncodified Section 7

issue could then help to determine if mitigation alternatives are needed and which method might be most effective. During the summer of 2000, data from 21 large cruise ships were collected. More limited monitoring occurred in 2001. Although some of these cruise ships did not participate in data collection in subsequent years[9], the 2000 data provide a useful basis for establishing typical discharge concentrations and a comparison to bacteria standards. A typical practice for cruise ships is to separate toilet waste (blackwater) from other wastewaters such as shower or galley water (graywater). While blackwater may pose a greater risk to public health than graywater, there is no consideration of sources of fecal coliform in water quality standards, and in 2000 gray water samples often had fecal coliform concentrations that were as high as blackwater. As a result, separation of the two discharges in this discussion in terms of impact on standards is not justified.

In the 2000 monitoring season, 94 black, 81 gray and 11 combined black and gray water systems were examined. The geometric mean of these data was 5,460 FC/100 ml, the median was 27,500 FC/100 ml and the range of values was from <2 to >16,000,000. Discharges were only allowed when the ships were underway[9]. Although 11 large ships were monitored in 2001, the data were similar.

Discharge of wastewater from a moving ship provides real benefit when considering the influence of the discharge on compliance with receiving water quality standards. The discharge from a fixed-point municipal sewage outfall relies on treatment to a certain level followed by dilution and dispersion of the discharge to mitigate potential environmental quality standards. As a ship moves through the water, the discharge is spread over a large area, hull displacement moves large amounts of water that fill in behind the ship and the propellers assist in mixing the discharge into the surrounding water. As a result, the concentration of fecal coliform or any other constituent discharged from a ship is directly influenced by ship speed and discharge rate.

Through literature review, fieldwork and evaluation of the EPA study which examined plume dispersion from a ship off Miami (2001), the SAP developed formulas for estimating dilution of wastewater discharged by a moving cruise ship. According to these formulas, a cruise ship traveling at a minimum speed of six knots and discharging up to 200 cubic meters per hour of wastewater would achieve a reasonable dilution of 1 part wastewater to 50,000 parts of ocean water. It is also expected that an additional dilution of 1:100 would be achieved by the time that discharge travels laterally one nautical mile, the minimum distance from shore that discharge is permitted under State and Federal regulations. Applying these formulas to the 2000 monitoring data demonstrated that there was about a 2% chance of exceeding a concentration of 400 FC/100 ml and about a 20% chance of exceeding a concentration of 43 FC/100 ml following the 1:50,000 dilution. There was no chance of exceeding even the most stringent shellfish harvesting standard of no more than 10% of the samples greater than 43 FC/100 ml and a median of less than 14 FC/100 ml following the estimated farfield dilution.

Because of the nearly instantaneous dilution behind a large cruise ship, it would be difficult for an individual to attain a significant exposure to wastewater contaminants. While it might be possible for primary contact a potential for secondary contact is more likely possible for a kayaker or jet skier. Alaska's water quality standard that would apply to this type of exposure is the secondary recreation standard. This standard is based on the geometric mean of a data set and is set at 200 FC/100 ml and is also violated if more than 10% of the samples in a 30-day period exceed 400 FC/100 ml. A ship's discharge would have to average about 10,000,000 FC/100 ml for multiple samples to cause an exceedence of the secondary contact standard after taking into account the dilution calculations, and it would have to do so multiple times a month. Such a scenario is unsupported by the 2000 and 2001 data considering the discharge restrictions placed on large cruise ships.

In addition to the effects of dispersion and dilution, the bacteria population discharged into the environment does not remain constant. Fecal coliform are adapt at living in a warm, dark, osmotic, balanced pH environment with an abundance of food. Following discharge into marine waters the population will begin to decline due to environmental stressors such as salinity, coagulation and flocculation, nutrient deficiencies, predation, bacteriophages, algae and other toxins [3]. Also, because bacteria have an electrostatic charge they tend to absorb to the surface of other charged environmental particulates or the air-water interface where they are then susceptible to settling or inactivation by solar radiation. Because all these environmental effects vary, a die-off constant is difficult to apply to the bacterial population. However because they do exist, they provide a confidence that the number of organisms reaching the shore under our analysis errs on the conservative side.

Cruise ship discharges should also be considered within the context of background fecal coliform from land-based sources. The number of fecal coliform excreted by warm-blooded animals, including humans, ranges from 10^9 to 10^{10} per gram of feces [2]. Aldersio and DeLuca [1] demonstrated that gull feces contained about 3.68×10^8 bacteria per gram and that goose feces contained about 1.53×10^4 per gram. They also reported that the volume of geese waste was typically 15 times that of the gull. Communities in Alaska where homes are on septic systems and are clustered along the shoreline present ample opportunity

[9]As problems with traditional wastewater treatment technologies became apparent, several large cruise ships elected not to discharge wastewater in Alaska in 2001.

for high levels of fecal coliform and potentially pathogenic microorganisms to be discharged into the waters. Runoff from snowmelt and rainfall [4] will contribute millions of fecal coliform per 100 ml from indigenous land animals wild and domesticated. Waters adjacent to marine mammal haul-out areas are also sources of fecal coliform. These background sources of fecal coliform complicate the water quality picture and in many cases result in fecal coliform concentrations higher at the shoreline than offshore.

III. CONCLUSIONS

Because Alaska's bacteria standards incorporate geometric mean or median values, or require multiple exceedences of a level of concern, they are not about worst case. Instead, these standards require multiple measurements over time, and tend to characterize a location. They are not written to be predictive of fecal coliform concentrations at any given time. The SAP concluded that effluent monitoring data demonstrated a very low probability that exceedences of the most stringent bacteria standard would result if the cruise ships are meeting the conditions of discharging at a speed of six knots at least one mile from shore. This was true even for the 2000 data, before cruise ships in Alaska elected to install advanced treatment systems or to discharge outside of the state's inland waters

Water quality standards are based on the monitoring of an indicator pollutant, fecal coliform. Viruses, protozoa and pathogenic bacteria strains are not measured. Presence of pathogenic microorganisms is dependent on the infection rate in the contributing population and survival of these other microorganisms will be different compared to the indicator bacteria. As a result, it is not impossible that a discharged pathogen could come into contact with someone recreating around a large ship or make its way into a shellfish bed. The SAP felt that discharges near shellfish beds could still be of concern.

Finally, the SAP also pointed out that there is some concern over the waste disposal practices of small cruise vessels. These vessels do not currently have holding tanks and, therefore, have to continuously discharge. Although the rate of discharge and the amount of discharge are not equal to those of large vessels there are discharges when at anchor. When stationary or drifting with the current the discharge from these vessels will be substantially less mixed. This will increase the potential for patches of contaminated water to cause exceedences of bacterial standards both near the vessel and in the direction of current flow. Under this scenario, there is significant potentially for humans recreating near the vessel to be exposed to fecal pathogens.

As a post script, data from the ships in the 2001 season show that well functioning onboard advanced treatment systems such the ultra filtration systems and the reverse osomois/disinfection systems can attain a mean fecal coliform concentration of 2 FC/100 ml, and a median value of 1 FC/100 ml with a range from 1 to 60 FC/100 ml.

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